Evaluation of Continuous Convection and Radiation Ovens in Automobile Cure Industry

R. Mehdipour[1,a],Z.Baniamerian[2,b,*] S. Sattar[3,c]

1,2 Assistant Professor, Department of Mechanical Engineering, Tafresh University, Tafresh, Iran 3 MSc Student, Department of Mechanical Engineering, Tafresh University, Tafresh, Iran

bamerian@tafreshu.ac.ir,

Abstract

Paint cure oven is one of the most important parts of automobile production line. The cure speed and the magnitude of energy consumption are significant in auto manufacturing industry. The radiation oven has been of the interest by cure industry due to the reduction in energy consumption and appropriate cure. The design process of these ovens is really complex specially for bodies with complex geometry and bodies which especially delicate to specific temperature condition. According to the progress of computation equipment abilities and design algorithms, the utilization of these ovens has gained considerable attention from auto manufacturing industry in recent years. This study considers the benefits and defects of the radiation oven and shows that replacement of the convection ovens with radiation ovens in Iran Auto manufacturing industry would lead to 32% energy saving. The design process of convection continuous ovens is easier than radiation ovens but the associated numerical modeling is complicated and computationally intensive. In this study, the moving boundary method and its application to convection continuous ovens are discussed. The numerical results based on the moving boundary method are compared with the experimental results.

***Keywords**: Radiation oven, Auto paint cure, Radiation heat transfer, Convection oven*

1. Introduction

Oven is a device that produces heat condition, appropriate for chemical and mechanical reactions in a body. According to this definition, many equipment such as stoves, heat treatment oven and chemical distillation towers, are called oven.

The continuous ovens are utilized for rapid cure of numerous products and require high amount of energy and time. Two types of oven named as batch and continuous ovens are available and prevalent in paint cure industry. However, in auto manufacturing companies that have mass production of similar models, the continuous ovens are affordable in cure period, product numbers, work force and wasted energy. Continuous oven is a kind of oven in which products are entered from one side of the oven and are exited from the other side continuously. The heat transfer in this kind of oven is generally accomplished by radiant and convection mechanisms. The complex geometry of the oven and its components as well as the number of parameters that affect the cure process makes the design of this kind of oven complicated.

In recent years the application of radiation oven with IR and UV rays has gained considerable attention due to the appropriate cure in comparison to the convection oven.

Nowadays, the utilization of these ovens is prevalent in industries such as printing on paper and CD, curing flat bodies. However, the usage of this type of cure is difficult for bodies with complex three dimensional shape, for instance, auto body. The design process of this type of ovens has became of interest from manufacturing industry as well as researchers. The result of research in this area is an oven design with above technology that introduced U Ford auto to the market in 2000 [1].The design of this type of ovens utilizes for complex geometry such as auto body and generally is based on trial and error. This method is usually time consuming and impossible to apply to problems with many effective parameters. Nowadays, due to the computer power progress, the researchers focus on the inverse methods more than others and several research have been conducted in this area [2-8].

Mehdipour et al. [9-11] propose an algorithm capable of prompt and efficient designing for cure ovens. Designing of paint cure ovens based on the cure window criterion is illustrated in [11]. Mehdipour et al. [11] discusses methods of defining the objective function . Influences of the objective function form on the procedure convergence as well as solution steps is also investigated. In order to improve the design procedure, a criterion called “Equivalent Isothermal Time” is identified and is demonstrated in [9]. This criterion reduces the number of optimization steps. Reduction of numerical costs is assessed in work of Ashrafizadeh et al. [10] by applying neural network and finite element method simultaneously.

In all mentioned works published by authors previously, the appropriate form of objective function is the most effective issue in the solution procedure. In the present study two issues are considered simultaneously, first complications in the geometry and second the most suitable form of the objective function.

In this study, after a full description regarding the procedure of paint cure and high amount of energy utilized in this process, design and manufacturing of radiation ovens for auto paint cure are discussed. The amount of energy saved using radiation oven instead of convection type is computed. Results show that the replacement of convection ovens with radiation ovens is satisfied. Therefore, suggestions are strongly made to auto manufacturing industry to utilize this technology for under construction ovens.

The challenging part of using radiation ovens is the design process and finding the best layout of heaters. In these ovens, radiation is the dominant mechanism for heat transfer. The layout of heaters for achieving uniform cure on the bottom surfaces of a body subjected to the heat or on the back surfaces of the body is difficult. In this study, the proposed methods for designing these ovens are presented.

Heat transfer mechanism is different for the convection and radiation ovens. In the convection oven, the oven air is heated first and then the heat is transferred to the body. As a result, the design process of this type of ovens is easier compared to the radiation ovens. However, the convection ovens have higher energy consumption. In contrast to design process, modeling of a convection continuous oven is difficult, due to the intense computations involved. In the present study, after a comprehensive comparison between the two ovens, the numerical method of moving boundary condition and how to apply it to auto paint cure oven is introduced. Using this method, we can model a 3-dimensional paint cure oven by prevalent computers within a reasonable time considering the complexity of body. The implementation of this modeling approach is illustrated for a real case and the results are compared with the experimental results.

1.1 Paint Cure and Painting Procedure

Continuous ovens are utilized in different industries. These ovens have been widely used in auto manufacturing and relevant industries, as well. In the auto manufacturing business, quality and manufacturing rate play an important role. Many researchers and designers have focused on the design of these ovens as the most common used ovens. Before reviewing the background study in this area, it is helpful to introduce the current procedure of auto body painting.

Auto painting usually passes through the following steps/instruments in the paint salon:

surface preparation (washing and body cleaning), phosphate, E-coat booth, E-coat oven, sanding, sealer booth, sealer oven, sanding, primer booth, primer oven, sanding top-coat booth, top-coat oven, final inspection.

Prior to any covering and painting in the paint salon, auto body needs to be washed in order to increase the paint adhesion and to prevent it from cracking. The body is washed in the alkaline solution without any chemical materials. This process is similar to the commercial carwash. Afterward, it is immersed in the zinc phosphate solution. Then, it is washed by water. Zinc phosphate prepares the body metal surface for painting with high quality [12].

After washing, the auto body is covered with an electrolyte (electro deposition (Ed)) coat. At this stage, the body is floated in the tank which is full of paint. Figure (1) shows the floating method in the paint tank. Afterward, the electric charge is imposed to interior and exterior body surfaces (in order to assist the coat to adhere to the body). Then, the body is washed by water in order to separate the unstable solid and slack part of the paint. Following the washing part, the auto body is entered to the ED oven for freezing the paint ingredient and preparing the body for the subsequent coating steps [12].

Auto body is cooled by passing through cold air tunnel, after exiting the ED oven. In the next step, the insulation of bottom surfaces of the auto body and the surfaces which are close to the road, such as side sealers, are accomplished. Moreover, the joints between the body components are sealed in order to prevent the water penetration and rusting. In this section, caulking putty is added to the interior and exterior parts of the body. Vibrating and acoustic insulators are also added to the interior parts of the body; afterward, the body is sent to the oven for curing.

Then, it is primer coat turn. The coating is applied to the interior and exterior surfaces by manual and automatic diffusion, respectively. Following to the interior and exterior coating, the body is transferred to the oven. The body is cooled by passing through the cold air tunnel and in order to detect the probable failures in the paint cover it is sent to the sanding section. The failure parts are repaired by sanding or painting operations.

Following to the primer coat step, the auto body is transferred to the top coat process. The final paint is included two main paint films, base coat and clear coat, which are applied in a successive manner. In this step the interior and exterior parts are coated by manual diffusion and diffusion robots, respectively (Figure2).

Fig. 1 Automobile in ED-coating step

Fig.2 Painting of the exterior part of the body by robot

In the next step, the body is entered to the oven and after exiting, it is cooled by passing through the cold air tunnel. Afterward, the body is gone through the inspection section and is polished.

In this step, the bodies with defects are sent to the previous step again. Therefore, the ordinary paint cover system in auto industry has 5 layers as follows: 1) Phosphate layer; 2) Electro deposition layer (ED); 3) Base or main coat layer; 4) Top-coat layer; 5) Clear coat layer.

Among different paint layers, generally the base coat and clear coat determine longevity of the paint [12].

The procedure explained in this section is the general process of auto body painting which could be generalized to the different auto manufacturing factories with minor changes in steps. These steps are illustrated in Figure (3). It is obvious that there are differences between these processes in the various factories according to the auto type and manufacturing necessity.

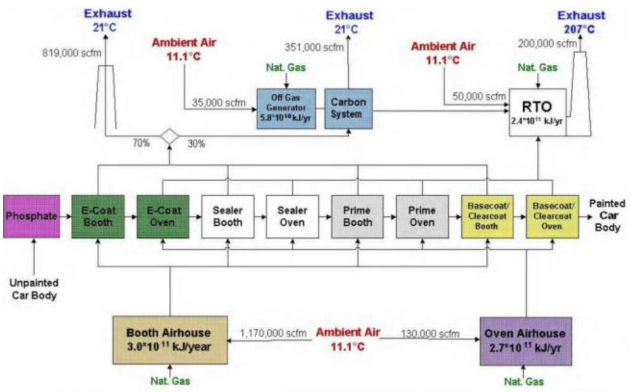

Fig. 3. Diagram of auto painting process [12]

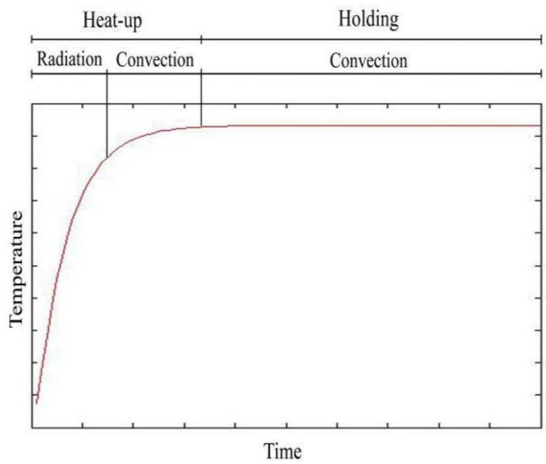

Fig. 4. A temperature-time model of a part of the body inside the oven

2. Convection Paint Cure Ovens

As mentioned in previous section, the auto body is sent to a continuous paint cure oven after each painting step to harden the paint. Continuous oven is a long tunnel with a rectangular section which the painted body is placed on a terrestrial or aerial rail. The heating process is completed by moving the auto body along the oven. The thermal system in the paint cure ovens is applied, based on heating with radiation, or convection heat transfer processes, or a combination of these two methods. In convection process, the hot air temperature of about 180 Celsius is the cause of cook.

The heating and curing process have two steps, holding and heat up. Following these steps and egress the body of oven, the third step, Cooling, will be conducted. The heat up step, usually includes convection and radiation heat transfer; whereas, the holding step is dominantly accomplished by convection heat transfer. Figure 4 shows the variation of temperature with respect to the point time on the body and also shows the sequence of the steps explained above.

In the initial part of oven, due to the paint wetness and the possibility of existence of solid particles in hot air, only heat transfer is utilized for the curing objective. Thus, the hot air is directed to a curve shape surfaces which is placed on side walls of the oven, and a part of heat up step is accomplished by the heat radiated from these surfaces. After passing through this area, we have the convection heat transfer area. In this step, the nozzles are placed in the casing of the oven, which direct the hot air into the oven. According to the oven design, these nozzles could have been located on the side or on the oven ceiling. The hot air exits of the nozzles and due to its high speed, it spreads within the oven. In the holding step, it is important to keep the temperature of the oven constant. . Thus, in the convection part, the air is circulated constantly and after heating, it is entered to the oven again. In order to circulate the air, the exhausters are placed in the ceiling of oven, which suck the inside air uniformly. This air is transferred to the out of the oven and majority of it is heated again inside the heat exchanger and go back to the oven. The rest of the air is voided in order to enter the fresh hot air.

Auto body is required to be cold following exiting from each step and before entrance to the next step. Hence, following the egress of the body from oven, the body is placed on a rail and is entered to the wind tunnel which is surrounded by numerous numbers of cold aerators. Due to the body motion on the rail among the aerators, the exited body temperature of oven is gradually decreased.

The presented painting process and utilized ovens are the ordinary system which is used in the current Iran auto manufacturing industry. The new furnaces which utilize the UV ray for paint cure have different structure and are explained in the following.

2.1 Modeling of Continuous Convection Ovens Applying Moving Boundary Method

Figures 5a and 5b indicate two views of a section of the oven which is of interest for simulation at this section. The oven is fairly long, about 150 m, and a large number of nozzles, about 1800, are installed on the side walls. Hot air exits the nozzles with the temperature of 490 K and velocity of about 15 m/s and touches the body which moves along the oven with a constant speed close to 5 m/min. The hot air stream in the oven is eventually collected and directed out through the egress holes at the ceiling.

CFD as the most popular modeling method is employed for simulation of convection oven in this study. A large number of grid points are required for an accurate numerical model of an real-scale problem, which has a high computational expense. Furthermore, a complex geometrical model needs to be avoided; considering the fact that a low quality geometrical model couldn’t be successfully exported to a grid generator. The preparation and discretization of the geometrical model is a pivotal and time consuming step. In this process, the number of panels in the model should be minimized, while no hole or overlap is allowed by the grid generator because of inducing great difficulties in the numerical solution process.

The body surfaces and the oven walls are covered with triangular meshes and the air flow field in the oven is discretized using tetrahedral cells. It is significant to note that the hot air nozzles with various sizes are arbitrarily arranged in different sections of the oven and, consequently, a full three-dimensional modeling of the problem is essential.

The computational grid assigned to the body is fixed and the walls of the oven are allowed to move in the opposite direction. Computer programs have been developed and connected to the main flow solver in order to execute the boundary conditions at the moving walls and also to transfer the boundary information into the field. At each time step, the right position of hot air nozzles with respect to the body and the fixed grid system are determined using the computer programs. The new positions of nozzles are used to implement the boundary conditions at each time interval. Figure 6 shows the moving boundary walls in three different time frames.

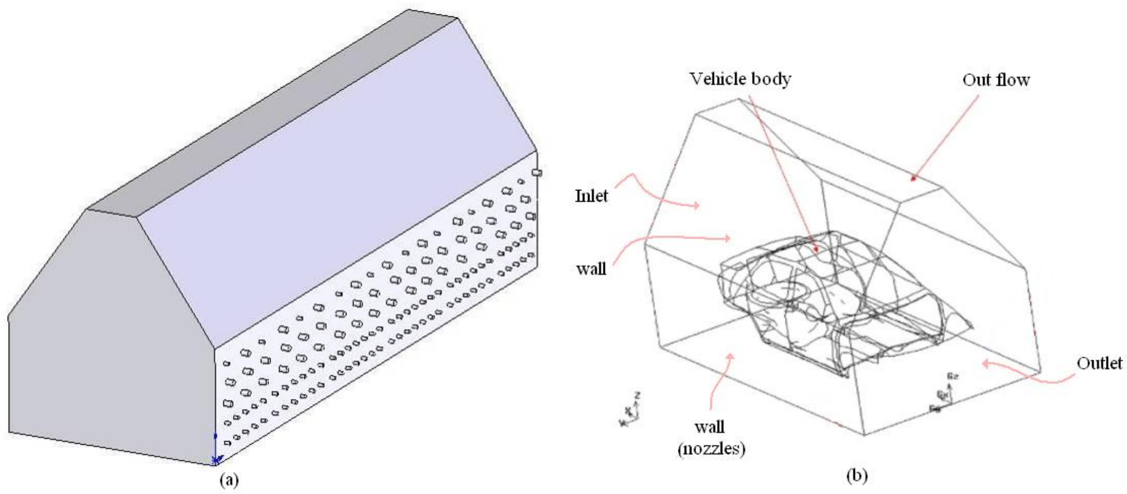

Fig. 5. (a) A section of the paint cure oven; (b) the body inside the oven

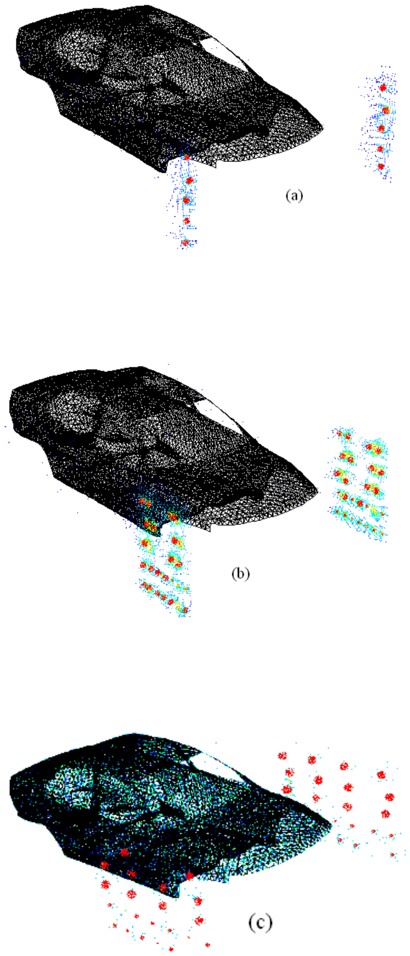

Fig. 6. Illustration of the variation of the positions of boundary nozzles after (a) 5 seconds, (b) 10 seconds, and (c) 30 seconds

The convection heat transfer coefficients at the elements on the body are determined by developing an auxiliary code. These coefficients are determined using the velocity field information from the CFD solution of the flow field. Consequently, the CFD solution together with heat transfer correlations calculates convective heat transfer.

The proposed algorithm calls a geometry modeller, a grid generator, a CFD software, a number of specifically written computer programs and a post processing software to carry out the simulation. Figure 7 shows the flow chart of the simulation.

Heat transfer occurs in the paint layer and throughout the body, while simultaneously the solvent is vaporizing. The phase change and the multi-dimensional conjugate heat transfer at the body surface cause more complexities. Discretization of the domain and numerical solution of the governing equations is essential to capture the complexities in the flow field and to thoroughly model the heat transfer phenomena. Additional complexities are also involved due to the scale of the problem and the transient nature of the procedure. The computational grid has a large number of nodal points. Each of these points has a number of unknowns associated with. The relative motion of the body with respect to the boundary walls imposes challenge to the numerical solution. Any attempt to modelling this problem needs geometrical as well as physical simplifications, hence, enough accurate solution is gained with a tolerable computational cost. The simplifications are discussed in the following.

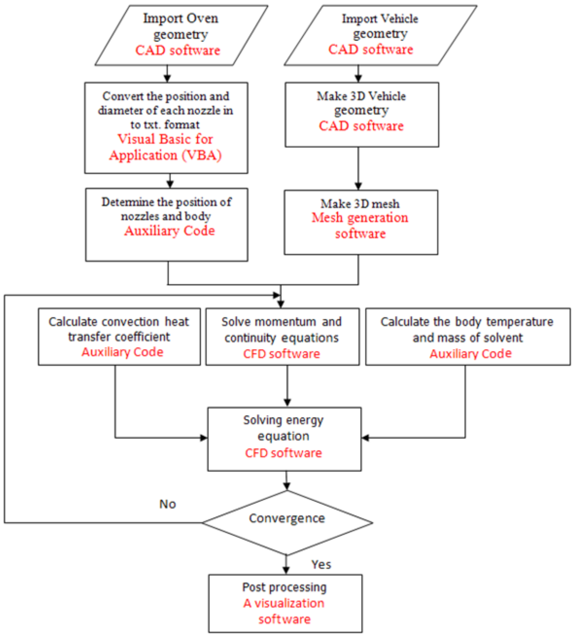

Fig. 7. The flow chart of the computational algorithm

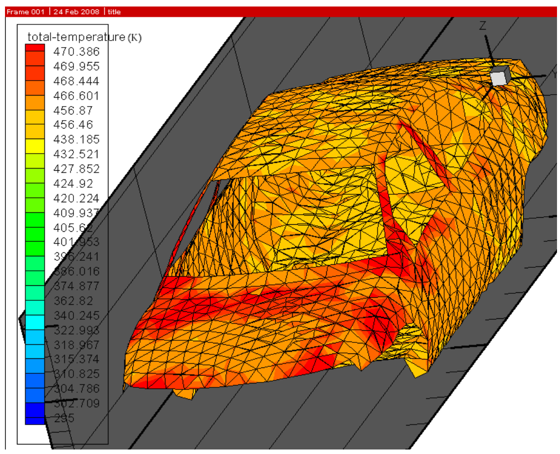

Fig. 8. Temperature distribution on the cured body

2.2 Results of Moving Boundary Model

The algorithm just illustrated is implemented to simulate the curing of the electro deposition coating on a 320 Kg body frame. Figure 8 shows the temperature distribution nearby the body at the end of the curing procedure.

The temperature history curves at a number of check points on the body are compared with the measured temperatures. The quantitative behavior of the determined temperature history curves is

satisfactory and the simulation results match well with the measured temperatures. A comparison between the empirical and simulation results at one of the check points is shown in Figure 9 the simulation error at a number of check points is indicated in

Figure 10 as well. It is observed that the relative error at all points is less than 8% .

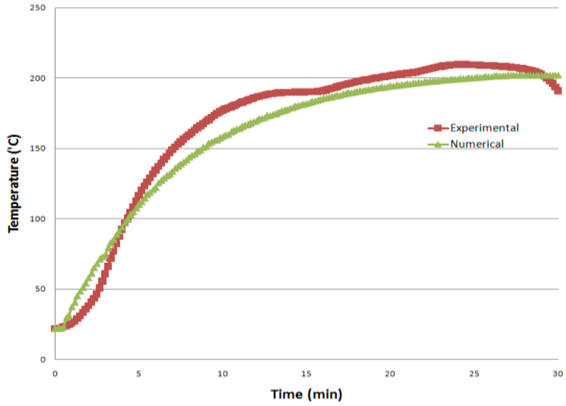

Fig. 9. Comparison between the experimental and numerical transient temperature at the left mudguard panel

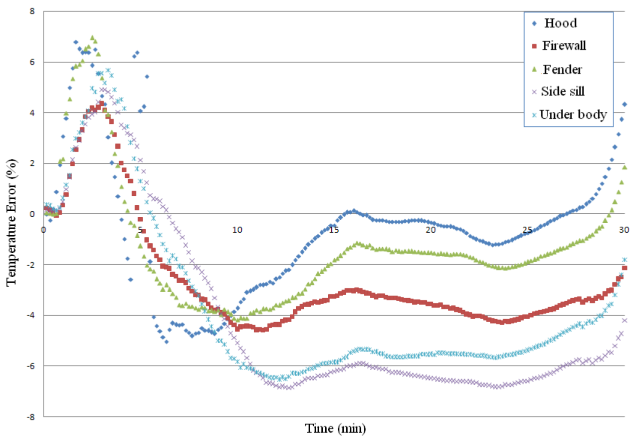

Fig. 10. Relative error in the calculation of temperatures at multiple check points on the body

3. RADIATION PAINT CURE OVENS

3.1 Benefits of Radiation Ovens

As mentioned, the application of the radiation ovens has gained significant attention in many industries. This attention is due to the several advantages of using this kind of ovens. These advantages are listed in the following:

1. Reduction of energy consumption: Inside of the radiation ovens is cooler in comparison with convection ones . The interior air in radiation ovens doesn't need to be heated due to the direct heat transfer from lamp to the body. The penetration of the ray to the body warms up the body.

According to the paint cure standard, for the ovens working with hot air, at each step of the air circulation, a portion of oven air needs to be replaced with the pure new air. Therefore, the low temperature of the radiation oven interior causes energy saving in the air ventilation step. The computations are presented in section 4.

2. Safety in explosion: Volatile materials in the paint is flammable and the interaction between these materials and the oven hot air is dangerous.

According to the standard, the density of volatile materials need to be less than its critical value. to pursue this requirement, a portion of the oven air has to be ventilated in every step. The low temperature interior of the radiation ovens decreases the explosion possibility in these ovens. As a result, radiation ovens are more secure than the convection ovens.

3. Desirable cure: Due to the UV ray penetration in the paint and heating the auto metal wall, paint cure in radiation ovens is started from the wall. Hence, the defects such as: blister, crinkling, and bubbling occur less. In addition, the penetration of the UV ray in the

paint layer improves the paint reactions as well as the adhesion between paint and the body.

4. Reduction of initial cost: Elimination of the burner and heaters from convection ovens and substitution with the radiation lamps reduces the initial cost. The penetration system and the burners of the convection ovens have high initial cost, which is higher in comparison with the cost of radiation ovens UV lamps.

5. Reduction of initiation time: One of the difficulties in using the convection ovens is the long time required for heating. Indeed, it is the time for preparing oven for admitting auto body. This time is considerably less in radiation ovens.

6. Increase in manufacture-line speed: Due to the higher ability of energy transfer in radiation ovens in comparison with the convection ovens, the curing time as well as the length of the radiation oven is shorter than the convection type.

7. Maintenance and repairing: Convenient service and maintenance and reduction in the cost and time in radiation ovens are significant. As a result, these ovens have been proposed in auto manufacturing industry. The most important problem in this industry is dealing with the surfaces with complex curvature. The U Ford auto has been launched to the market in 2000 which was applied the UV ovens method for paint curing [1]. This method has been used for other auto bodies after 2000.

3.2 Defects of Radiation Ovens

Considering the advantages of using the radiation ovens, the question is why this kind of oven did not become popular. In order to respond to this question, we need to consider the disadvantages of using the radiation ovens, as listed in the following.

1. The health danger of UV ray: The UV ray penetrates well in the paint. Likewise, it penetrates into skin and causes skin damage and cancer. It should be noted that this problem is severe for single ovens. However, in continuous ovens the health danger problem is not critical due to the long distance between the human working area and cure areas.

2. Complexity of the radiation oven design: In the convection ovens, the air around the auto body is heated and the heat transfers to the body. As a result achieving a uniform auto body cure is easy. In the radiation ovens, most of the heat is transferred through the radiation and as a result, design and finding the appropriate arrangement of the heaters in order to achieve desirable cure is complicated. Considering the auto models, which have utilized the radiation oven for their paint curing, shows that designers of these ovens were more successful in design of autos with low curvatures (such as truck). However, design of these ovens was not much successful for vehicles which usually have highly curved bodies. Since the auto body geometry has curvature in three dimensions, the application of flat lamps does not lead to a desirable cure.

This new technology has been of interest for auto industry. For instance, Daimler-Chrysler company has utilized robot to apply this method. However, using robots bring complications to the curing process.

4. Comparison of Convection and Radiation Type Ovens from The Viewpoint of Energy Consmption

At this section, by using the heat transfer equations, it is claimed that utilization of the radiation ovens in Iran auto industry causes a considerable reduction in energy consumption. Computation of heat transfer can be divided into 5 steps:

1) Required heat for the fresh air substitution; 2) Heat loss of wall; 3) Energy required for paint cure; 4) Thermal load of hangers; 5) Thermal load of conveyer. Each of these steps is discussed in detail, in the following:

4.1 Required Heat for the Fresh Air Substitution

The air inside the oven is ventilated at each step and some is replaced by fresh air. This ventilation is required due to the existence of volatile material and in order to avoid reaching to the critical density of these materials, defined by the standards, inside the oven. The amount of the fresh air depends on the proportion of solution materials in the paint. The low limit of the density required for explosion is 25%. ED oven requires 5.2 kg/m^2 fresh air up to the maximum of 5.6 kg/m^2 [13] for each layer of paint. The magnitude of required energy for heating the fresh air to get its temperature to the temperature of the oven can be determined by the following equation [13]:

$$Q = DAc(T_I - T_a) \quad (1)$$

Where T_I and T_a denotes the temperature of inside and outside of the oven, respectively, A is the auto surface area, c is the heat capacity, D is the required air per square meter unit of painted surface. In radiation ovens, heat transfers from body to the air causes the temperature increase in the air, however, in convection ovens, the hot air around the body causes the paint cure. Generally, inside the radiation oven is colder than the body. As a result, the combustion probability is lower which leads to the lower need of fresh air as well as the number of ventilation cycles. In this study, we assume the magnitude of ventilated air remains constant as a conservative assumption. To calculate the temperature in a radiation oven, first of all, the heat transfers in radiation oven and the convection heat transfers from auto to the inside of the oven need to be computed, based on Equation (2).

$$C_i \frac{dT_i(t)}{dt} = Q_{i,rad} + hA(T_i - T_I) \qquad (2)$$

In this equation, T_i denotes the temperature of body and $Q_{i,rad}$ is radiated energy from heaters and h is the convection coefficient within the oven.

We assume the temperature inside the oven to be reached to the steady value and air ventilation does not cause the temperature variatio1n in the oven. Likewise, we assume that the heat transfer from the body to the oven air supplies the required energy for heating the fresh air per an auto body. The convection heat transfer between the curing body and the oven air inside, computed using Equation

$$Q_1 = \sum_{i=0}^{t\_out} hA(T_i - T_{in})dt = DAc(T_a - T_I) \qquad (3)$$

Equation (3), in fact, demonstrates heat loss due to the heat transfer from the body to the oven interior.

In order to have a direct comparison between the convection and radiation ovens, the paint cure quality in both ovens needs to be the same. In order to satisfy this requirement, we assume the radiation energy is determined such that the variation of auto body temperature with respect to time is similar to the convection oven [14]. The oven temperature is computed using Equations (2,3)……. and discretesizing the auto body motion to the small time steps.

4.2 Heat Loss from Walls

By considering the manufacturing cost, the oven wall is selected such that has the least heat transfer to the outside. The heat transfer from the wall to the outside is computed based on Equation (4).In this equation, UA_w denotes the thermal resistance.

$$Q_3 = UA_W(T_I - T_a) \qquad (4)$$

4.3 Energy Required for Paint Cure

The energy used for the paint cure is the sum of energy required for heating paint and metal body, such that the desirable cure is obtained. This process includes boiling of the solvent and its evaporation inside the oven. The energy required for the paint cure is determined based on Equation (5).

$$\begin{aligned} Q_4 = {} & m_b c_b (T_a - T_b) + d_w A[c_{l,w}(T_a - T_{bo}) \\ & + h_{fg} + c_{g,w}(T_{bo} - T_I)] \end{aligned} \qquad (5)$$

Where, h_{fg} denotes the latent heat of evaporation for volatile material, d_w is density of volatile material in every painted square meter, m_b is mass of auto body, and T_{bo} is the boiling temperature of volatile materials.

4.4 Thermal Load of Carrier and Conveyer

For each auto body which enters the oven, There is a mass corresponding to the carrier and conveyer system. This extra mass also absorb the heat from the oven. In convection oven, controlling the heat flow is hard and the heat transfers from the air to these equipments. However, in radiation ovens, the heaters radiate to the body; heating the body causes heating the inside air of oven and the hot air of oven is the cause of heating the equipment. In this heat transfer process, heat transfers from the reservoir to the equipment, by more intermediate stages involved and as a result the equipment temperature is less than the body. The required energy for both ovens can be calculated using Equation (6). To simplify the computation, we assume the inertia time in the oven is equal to the time required to achieve the equivalent temperature of equipment and inside of the oven. In Equation (6), m_h and m_c denote the carrier and conveyer mass, respectively.

$$Q_3 = (m_h c_h + m_c c_c)(T_i - T_a) \qquad (6)$$

Table (1): Values of implemented coefficients in the heat transfer calculations.

Temperature of inside area of convection oven(K)	493	inertia in convection oven (min)	20
Temperature of inside area of radiation oven(K)	382	the ratio of curing body (auto) mass to its section area (kg/m^2)	6.13
Average area of auto (Samand) (m^2)	80	the ratio of mass of water containing in paint to the paint coating area (kg/m^2)	0.34
Required fresh air per painted surface(kg/m^2)	6.5	Curing body (here, steel) heat capacity (J/kgK)	480
Fresh air mass per auto (kg)	520	latent heat of evaporation (J/kg)	2263073
Convection oven inertia	30	air heat capacity (J/kgK)	1011

Table (2): The magnitude of energy consumption for a Samand auto body in a convection and radiation ED ovens.

ED oven percent	radiation	Convection	% change of required energy	%savings compared to the convection oven
Required heat for fresh air (kJ)	42699	101464	57.9	24.1
The absorbed heat in a body (kJ)	40723	40723	0.0	0/0
The absorbed heat in leakage material evaporation (kJ)	70313	75999	7.5	2.3
Thermal load absorbed by hangers and conveyer thermal load (kJ)	9747	2076	53.1	4.5
Loss heat of walls of oven(kJ)	1.2	57.9	5003	2105
total (kJ)	32.1	32.1	24394	165587

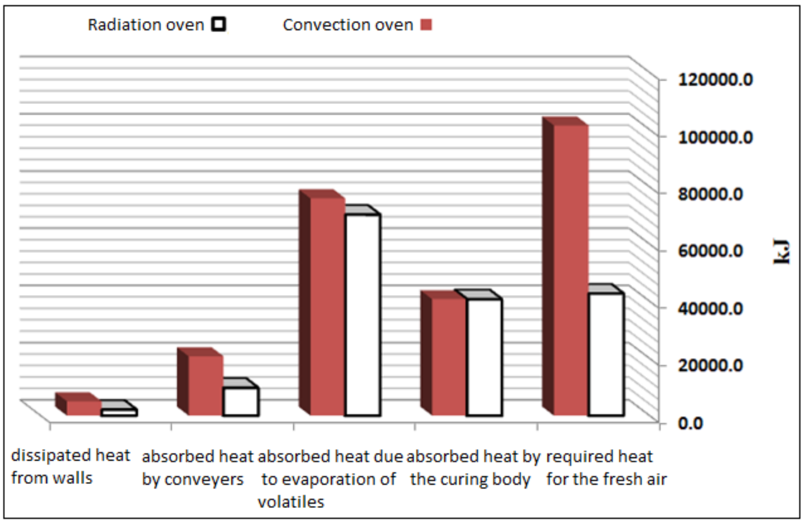

Fig. 11. Estimate of consumed energy in convection and radiation ovens for paint cure on Samand automobile

5. Results and Discussion

The accomplished model is based on thermodynamic, thermal equilibrium and defined equations. Some of the utilized coefficients are summarized in Table (1) and the final results of required energy value for an auto in the ED oven are presented in Table (2). The proportion of energy saving due to the utilization of radiation oven is indicated in Figure 11 the energy required for an auto in an ED oven with radiation and convection heat systems are reported in table (2). With respect to the lower operating temperature and solvent substances density in sealer and lining ovens, the prominent contribution of dissipation corresponds to ventilation.

According to the results, it can be stated that more than 32% in ED ovens and at least 50% in other types of ovens can be saved by reforming the oven based on what mentioned in this study.

The most important problem in these ovens is finding the best arrangement of heaters. The inverse and optimization methods are proposed to fix this problem.

6. Conclusion

This study made a comparison between the radiation and convection ovens. Moreover, the benefits of the paint cure by radiation ray and especially UV ray have been investigated. Convection ovens employing boundary moving method is simulated for curing a 3-dimensional geometry of an auto. Finally, the amount of the energy saving in radiation oven is computed by heat transfer computations, considering the lower temperature within the radiation ovens. The calculation shows, 50% energy saving would be achieved by using radiation ovens instead of prevalent convection ovens.

Considering the recent advances in design of radiation ovens, this study proposes the usage of radiation ovens for auto manufacturing industry in Iran. The cost of replacing the convection ovens with the radiation of ovens is acceptable and justified considering the amount of auto production in Iran.

Nomenclature

A	Auto surface	m_c	Mass of conveyer
C	Heat capacity	m_h	Mass of hanger
d_w	Density of leakage substance per square meter of painted surface	$Q_{i,rad}$	The magnitude of confirmed energy from heater
D	Magnitude of air per square meter of painted surface	T_a	Temperature of outside the oven
h	Convection coefficient inside the oven	T_I	Temperature of inside the oven
h_{fg}	Latent heat of evaporation for leakage material	T_i	Temperature of body
m_b	Mass of auto body	UA_w	Thermal resistance of oven wall

References

[1]. Mills, P. (2005). Robotic UV Curing for Automotive Exterior Applications A Cost-effective and Technically Viable Alternative for UV Curing. New York: Surcar.

[2]. Daun, K., Francis, F., Larsen, M., Leduc, G. and Howell, J.R. (2006). Comparison of Methods for Inverse Design of Radiant Enclosures. Journal of Heat Transfer, 128, 269-282.

[3]. Daun, K.J., Howell, J.R. and Morton, D.P.(2003). Geometric Optimization of Radiative Enclosures Through Nonlinear Programming. Journal of Numerical Heat Transfer, 43, 203–219.

[4]. Daun, K.J., Howell, J.R. and Morton, D.P. (2003). Geometric Optimization of Radiant Enclosures Containing Specular Surfaces. Journal of Heat Transfer, 125, 845-851.

[5]. Daun, K.J., Howell, J.R. and Morton, D.P. (2003). Design of Radiant Enclosures Using Inverse and Non-linear. Inverse Problem in Engineering, 11, 541–560.

[6]. Francis, H.R.F. and Howell, J.R. (2004). Transient Inverse Design of Radiative Enclosures for Thermal Processing of Materials. Inverse Problem in Design and Optimization, Symposium Rio de Janeiro, Brazil.

[7]. Erturk, H., Ezekoye, O.A. and Howell, J.R. (2004). Boundary Condition Design to Heat a Moving Object at Uniform Transient Temperature Using Inverse Formulation. Journal of. Manufacturing Science and Engineering, 126, 619-626.

[8]. Daun, K.J., Howell, J.R. and Morton, D.P. (2003). Geometric Optimization of Radiative Enclosures Through Nonlinear Programming. Journal of Numerical Heat Transfer, 43, 203–219.

[9]. Mehdipour, R., Aghanajafi, C. and Ashrafizadeh, A. (2012). Optimal design of radiation paint cure ovens using a novel objective function. Pigment & Resin Tecnology, 41, 240 - 250.

[10]. Mehdipour, R., Aghanajafi, C. and Ashrafizadeh A. (2012). Hybrid optimization algorithm for the thermal design of radiation paint cure ovens. Applied Thermal Engineering, 40, 56-63.

[11]. Mehdipour, R., Ashrafizadeh A., Daun, K.J., and Aghanajafi, C. (2010). Dynamic optimization of a radiation paint cure oven using the nominal cure point criterion. Drying Technology, 28(12), 1405-1415.

[12]. Methier, R. (2003). Notice of Mact Approval. SIP Permit, Application No. 14178, State of Georgia, Air Protection Branch, May.

[13]. Data of Durr company for the process design of Irankhodro ovens

[14]. Ashrafizadeh, A. Mehdipour R. and Rezvani, M.(2008). Design, simulation and thermal analysis of an ED oven. Mechanical Engineering Conference, Bahonar University, Kerman, Iran, May.